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On

THE EFFECT OF MOISTURE AND FUNGUS ON ELECTRICAL AND MECHANICAL PROPERTIES OF PLASTIC INSULATING MATERIALS.

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Tropical Deterioration Administrative Committee

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Electrical and Mechanical Properties
of Plastic Insulating Materials
October, 1945

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THE EFFECT OF MOISTURE AND FUNGUS ON ELECTRICAL AND MECHANICAL PROPERTIES OF PLASTIC INSULATING MATERIALS

Survey of Work which is being done in this Field.

Declassified to Open Jan 18, 1946

Introduction

In June 1945, the Johns Hopkins University undertook an experimental investigation for the National Defense Research Committee with the object of studying the problem given in the main heading of the present report. The request for such an investigation originated with the Services which are all interested in this vital problem. In connection with the experimental work, it was deemed desirable to make a survey of what has been done, along these lines, by others. Such a survey falls naturally into three parts:

1. Compilation of a bibliography of all references to published material. This is straight library work.

2. Getting together available data on recent work done in Service laboratories and manufactures' laboratories which for various reasons have not been published.

3. Making a critical study and evaluation of all pertinent material made available. The report on such a study would logically come towards the end of the experimental work now going on at Hopkins, for it is to be expected that the evaluation can be made more intelligently in the light of experiences gained in that experimental work.

The present report deals with the second part of the survey referred to above. It is decidedly not complete, but it is written at this time because the end of the war brought with it the termination of NDRC sponsorship of our experimental investigation as of October 31, 1945.

Inspection of Service Laboratories and Manufacturers' Laboratories.

In order to get information of the type mentioned under Point 2 above, the writer made a series of visits to various laboratories during July and August of this year. It was thought that these inspection trips might also yield information which would be of immediate use in the experimental work being done at Hopkins. The following places were visited.

Army Electronics Standards Agency, Red Bank, N.J.
Signal Corps Laboratories, Fort Monmouth, N.J.
Materials Laboratory, New York Navy Yard, Brooklyn, N.Y.
Works Laboratory, General Electric Company, Schenectady, N.Y.
Plastics Laboratory, General Electric Company, Pittsfield, Massachusetts
Bell Telephone Laboratories, Murray Hill, N.J.
Belmont Radio Corporation, Chicago, Illinois
Formica Company, Cincinnati, Ohio.
Wright Field, Dayton, Ohio
Micarta Plant, Westinghouse, Trafford, Pennsylvania
Synthane Corporation, Oaks, Pennsylvania

The measurements of Dr. Curtis showed that the volume resistivity in general varies with the humidity of the surrounding atmosphere, and furthermore, that it takes a long time before equilibrium conditions are reached. Fig. 1A shows his results for some of the materials investigated. These results were selected because they are representative of the different types of insulating materials under the conditions of the experiment. The specimens had all been kept for over a month in a humidity chamber where the relative humidity was about 90%; then the humidity in the chamber was lowered to 25% and kept at this value for more than a month with the temperature at 25°C. Measurements of volume resistivity were made during this latter period at the lower humidity, and the curves show the striking effect of the drying out of the different materials. The ordinates are relative resistance values, and the figure gives the relative rate of recovery of volume resistivity for the different materials; with different type of specimen and electrode arrangement the absolute rates of recovery presumably would be different. The important point to note is that, under conditions such as these, the volume resistivity is rather indefinite, and it is not practicable to determine the change in volume resistivity with humidity.

When surface leakage is measured on a solid dielectric the current flows partly in a surface film on the dielectric and partly through the dielectric itself. It is customary to define surface resistivity as the resistance between opposite edges of a surface film which is one cm square. Now, if the volume resistivity of the film is defined in the usual way as the resistance between opposite faces of a one cm cube made out of the material of the surface film, then it follows that for a film of thickness t:

$$\sigma = \frac{\rho}{t}$$

where σ is surface resistivity of the solid dielectric and ρ volume resistivity of the material of the film. Hence, the surface resistivity, as defined, is not, strictly speaking, a constant of the material of the film, for it depends on the thickness of the film. However, both the thickness t and the volume resistivity ρ of the film depend on the nature of the solid dielectric surface, and therefore it is permissible to speak of surface resistivity of a dielectric under given conditions as a constant of the dielectric. It is necessary, in principle, to correct measured values of surface resistance for the effect of the current that flows through the dielectric itself. This can be done if the volume resistivity of the dielectric is known, but in general the correction is inappreciable .

While it is not feasible to determine the relation between the relative humidity of the surrounding atmosphere and the volume resistivity of a particular solid dielectric because of the slowness with which equilibrium is attained, conditions are different for surface resistivity. Here, too, it takes time for the equilibrium to become established, but not as long as in the case of volume resistivity. Fig. 1B shows how the surface resistivity of hard rubber varies with time after the relative humidity of the surrounding air is raised from 50% to 93%. The drop is very rapid within the first couple of hours after the change, and the resistivity is still going down after 18-20 hours, although considerably more slowly. If a sample is kept in an atmosphere of a given relative humidity for 18 or 20 hours before a measurement is taken it becomes feasible, then, to establish an approximate relation between relative humidity and surface resistivity. The paper gives a great many curves showing this relation for different materials, of which those in Fig. 1C are typical. However, it should be pointed out that surface resistivity does not become stabilized in 18-20 hours, as can be seen in the three curves for hard rubber, red fiber and bakelite given in Fig. 1D. These samples had been kept in air of 95% relative humidity. Then the humidity was lowered to 29% and the initial resistance measured after 48 hours. Dr. Curtis remarks that "precise results are of little value in the practical use of insulators", considering the changes in resistivity which take place when the humidity of the surrounding air varies.

There is an interesting discussion on the nature of surface leakage, in this paper. It has been assumed that surface leakage is due to conductance of a moisture film with perhaps other material on the surface of the dielectric. Various investigators have determined the thickness of the films of water deposited on the surface of substances such as quartz and glass for different values of relative humidity in the surrounding air. Thus, for carefully cleaned quartz it has been found that the thickness of the film in air of 90% relative humidity is about 5×10^{-7} cm. The surface resistivity is approximately 10^{12} ohms. This gives a conductivity of the water in the film of 2×10^{-6} mho per cm, which is of the same order as that of distilled water. With quartz specimens which had not been cleaned the film thickness at 90% relative humidity was found to be from 10^{-6} to 6×10^{-6} cm. Taking the highest value of film thickness and the lowest value of surface resistivity observed (10^{8} ohms) the conductivity of the film turns out to be 0.0017 mho per cm. This high value of conductivity (compared to that of distilled water) must be due to salts on the surface of the quartz dissolved in the water. It would only take 6×10^{-9} grams of sodium chloride per square cm of the surface to account for it, a degree of contamination which is easily brought about by handling. It is pointed out that the presence of salts on the surface of hard rubber does not affect the surface leakage at extremely low values of relative humidity. This again suggests that the surface conductance at high humidities is caused by salts dissolved in a water film.

Recent Experimental Work

I. Insulation Resistance
A. Effect of Exposure to Air of High Relative Humidity

Against the background of this excellent study of thirty years ago, we shall now look at some of the recent work. Fig. 2 gives, in the form of graphs, the results of experiments carried out at the Bell Telephone Laboratories. The figure is completely self-explanatory except for some details about the conditions of the experiments. The specimens used were in the form of rectangular terminal strips, each strip having seven small metal eyelets on each side, uniformly spaced about 1/4 inch apart. Alternate eyelets were connected together, the two groups of each strip thus forming the electrodes and giving a rather complex leakage path. The strips were suspended by the connecting wire in a humidity chamber, one group of interconnected eyelets from each strip being tied to a common ground, the other to terminals passing through the wax seal of the chamber. The humidity in the chamber was maintained at the desired value by using a suitable salt solution.

After the strips were in position they were inoculated with a fungus (poria incrassata). No special effort was made to clean the specimens which were cut from ordinary stock material. The specimens therefore started out with the normal surface contamination, and the poria incrassata fell a prey to other fungi, spores of which must have been present on the surface.

The direct current resistance was measured at 100 volts, initially at room conditions and later as indicated. It is, of course, impossible in this case to distinguish surface conductance from volume conductance, and the resistance values given reflect the combined effects. The drop in resistance during the early part of the test is in qualitative agreement with results of the paper by Dr. Curtis. The initial sharp drop in the case of methyl methacrylate is ascribed by the authors to condensation (visible condensation?) on the surface.

After 58 days an attempt was made to stimulate fungus growth (which, still was rather meagre) by causing rapid condensation on the surface through a sudden lowering of the temperature to 15°C. The resulting momentary rise in resistance is interesting though unexplained.

After 214 days a study of resistance recovery under decreasing values of relative humidity was begun. It is interesting to notice that the recovery was complete for methyl methacrylate (lucite), though not for the other specimens (which may perhaps be explained by a lag in the recovery of volume resistance). The most striking result of this experiment is the demonstration that the fungus which was present on all specimens did not prevent recovery of the insulation resistance as the samples were dried out under the lower humidities. However, the presence of the fungus caused the insulation resistance to deteriorate more rapidly when the humidity was raised to its original value, as can be seen very clearly in the case of the lucite specimen. It should be noted that the abscissa scale in Fig. 2 is enlarged after 270 days. The deleterious effect of fungus appears to be like that of any other surface contaminant which increases the absorption of moisture.

The curve for lucite in Fig. 2 shows a few more or less definite breaks in the beginning which appeared to bear some correlation with the growth of fungus as observed visually. The authors, following this lead, started another test with four lucite samples. However, because of different conditions as to electrodes etc., it is difficult to compare the results of the two series of tests. The results of still another experiment, showing the relative behavior of methyl methacrylate and phenol fabric at 97% and 100% relative humidity, are given in Fig. 3. The distinction between the two materials is quite sharp at 97% relative humidity but wholly blurred at 100%.

The principal conclusion drawn by the authors from this work is that differentiation between the effects of moisture and fungus on surface resistance can be made for high quality insulating material at 97% but not at 100% relative humidity. On commercial filled plastic the effect of moisture is of such a magnitude as to mask any effect of fungus.

Fig. 4A shows some results obtained at the Belmont Radio Corporation. The specimens were 2 inch square and the electrodes were two 6-32 screws with lock-washers, 1 inch apart. The insulation resistance measurements were made with 540 volts. Each point represents the average for 4 samples.

The curves in Fig. 4B are drawn on the basis of data from the Synthane Corporation.

An investigation was made in the Signal Corps Laboratories at Fort Monmouth on the effect of certain conditionings involving rather complex humidity and temperature cycles. The specimens were discs of 4 inch diameter and 1/8 inch thickness made from molded phenolic material (MTS-E-3, MFE) and the volume resistivity (ASTM, D257-38) was measured at intervals in the cycling. The specimens were subjected to a total of fifteen 24 hour cycles made up as follows:

	a)	4½ hours at 65°C, 95% RH
	b)	2 " cooling to 25°C, 95% RH
	c)	2½ " at 25°C, 95% RH
	d)	4½ " " 65 ", 95% RH
Humidity	e)	2 " cooling to 25°C, 95% RH
Cycle 1.	f)	4½ " at 25°C, 95% RH
	g)	3 " at -10°C
	h)	1 " at 25°C, 95% RH

The specimens were removed from the conditioning chamber during step f, in the fifth, eleventh and fifteenth cycle and tested immediately. The following results were obtained for two samples (identified as #6 and #17), the values of resistivity being given in ohm cm:

	Resistivity			
	Initial Value	5 cycles	11 cycles	15 cycles
Sample #6	2.3×10^{12}	7.4×10^{11}	5.6×10^{11}	7.4×10^{11}
Sample #17	2.5	9.2	6.6	6.9
Average	2.4	8.3	6.1	7.2

Two other samples were subjected to fifteen cycles which differed from the preceding in the latter stages:

	f)	1½ hours at 25°C, 95% RH
Humidity	g)	3 hours at -10°C
Cycle 2.	h)	2 hours at 75°C
	i)	2 hours at 25°C, 95% RH

These specimens were also removed during step f in the fifth, tenth and fifteenth cycle and tested at once. Results:

	Resistivity			
	Initial Value	5 cycles	10 cycles	15 cycles
Sample #2	3.3×10^{12}	8.4×10^{11}	2.1×10^{12}	6.1×10^{11}
Sample #23	2.8	5.8	3.7	4.3
Average	3.1	7.1	2.9	5.2

It is obviously difficult to interpret the results of tests such as these. There was another series of tests on the same type of material where the humidity cycle was as follows:

Humidity	6 hours at 55°C and 95% RH
Cycle 3	6 hours at 26.5°C and 95% RH

The specimens were dried for 48 hours at 50°C before being subjected to the humidity cycling, and for 128 hours at 50°C after completing 26 cycles. Measurements of volume resistivity were made at intervals during the whole test. However, the results are even more erratic than those shown above and they will not be given here. These tests were only a part of a larger program conducted at Fort Monmouth with the object of determining the relative severity of humidity and water immersion conditionings in terms of their effect on electrical characteristics such as volume resistivity, power factor and dielectric constant. Some of the results on volume resistivity have been included here because they come under the general category of the effect on insulation resistance of exposure to air of high humidity.

There is only one other item in this category among the data which have been made available; it comes from the Aircraft Engineering Laboratories at Wright Field and deals with the effect of exposure to air of 100% RH and 40°C on the insulation resistance of "linen phenolic strips". The strips were 2 1/4" x 1/2" x 1/8" with 1/4" holes and washers spaced 1/2" apart. Measurements of resistance were made during the first 60 minutes after the strip was placed in the humidity chamber. The resistance of the dry strip was 60000 megohms; ~~after~~ in the humidity chamber the resistance dropped extremely fast as shown in the table below.

1 minute	1000 megohms
2 "	100 "
5 "	6 "
10 "	3 "
30 "	1 "
60 "	1 "

According to these data the resistance of the strip dropped to one hundredth of one per cent of its original value in five minutes, and during the last half hour of the test there was no measurable change.

B. Effect of Condensation

When an insulator is kept in a humidity chamber with a certain high relative humidity, for example 90%, then, under equilibrium conditions , there will be a certain amount of moisture in its surface film, as mentioned in the review of the paper by Dr. Curtis. If the temperature of the insulator initially is considerably below that of the chamber, then a much heavier layer of moisture will be temporarily deposited on the surface, usually as visible condensation. This heavy layer of moisture will lower the surface resistance to a certain minimum value, and then as the condensed moisture begins to evaporate again, the insulation resistance starts rising, gradually approaching the value corresponding to equilibrium conditions in the humidity chamber. It has generally been assumed that this minimum of insulation resistance under condensation will be independent of the original resistance of the insulator, since the effect of a heavy layer of water should be predominant. Some very interesting studies made at the Bell Telephone Laboratories show, however, that this is too simple a view. The samples used in the experiments were phenol plastic terminal blocks having six terminal punchings with barriers between adjacent ones. Alternate terminal punchings were connected in parallel, the two groups thus constituting the electrodes between which the insulation resistance was measured. Two terminal blocks were placed in the humidity chamber at the same time, both mounted horizontally, one with the punchings horizontal and the other with the punchings vertical. A series of condensation tests was made with these two specimens in which the initial value of the insulation resistance was varied from 33 to 38400 megohms. This wide range in initial resistance was attained by either drying the samples at about 50°C or keeping them in an atmosphere of 90% relative humidity for different lengths of time before they were chilled in refrigerators. All measurements of insulation resistance were made while the specimens were covered with moisture condensed on their surface after they were placed in a chamber of 90% RH, at about 30°C. Test results are shown in Table I.

In the light of what has been said above concerning the preconditioning of the specimens the results seem to indicate that the insulation resistance under condensation depends significantly on the state of dryness of the insulator before condensation takes place. A natural explanation would be that the continuity of the film of condensed moisture is greater when the surface is damp initially than when it is dry. Photographic studies made in connection with the experiments seem to bear out this view.

C. Effect of Immersion in Water

To study the effect of water immersion on insulation resistance samples of the material in question are kept in water of a certain temperature and taken out at intervals for measurements. Before the measurements are made, the surface is wiped with a cloth to remove the water. The deterioration of insulation resistance is thus essentially a measure of the water absorption into the body of the material.

In Fig. 5 are shown the results for four different materials from a series of tests made at the Formica Company. The progressive deterioration of insulation resistance is shown for water immersion lasting 150 days. The samples were 3" x 2" x 1/2" and the electrodes were Pratt and Whitney tapered pins 1" apart, inserted from opposite sides. The immersion was in distilled water of 50°C. Before being measured the samples were kept for 1/2 hour in distilled water at room temperature. They were thereupon wiped off, first with a damp cloth and then with a dry cloth. A potential difference of 150 volts was applied for one minute between the electrodes and the measurement was completed within two minutes after the samples were removed from the water.

The graphs have been plotted with logarithmic scales. It is interesting to note the difference in the relative rate of deterioration. If the insulation resistance after 1 day immersion is taken as reference, then the time required for a drop to 1% is as follows, for the different materials:

XX	6 days
XXX	10 days
GBE	20 days
L (melamine)	200 days (extrapolated)

From Belmont Radio Corporation we have the following data on insulation resistance versus time of immersion in tap water of the same two materials shown in Fig. 4A.

I.R. in Megohms

	Initial	4 hours	1 day	2 days	5 days	7 days
PBG	10^6	45000	30000	27000	24000	10000
GMG	230000	7.5	5.2	4.2	1.2	

Samples and electrode arrangement were as described above, for the humidity exposure tests.

Immersion tests on several grades of laminated phenolic material have been made at the Signal Corps Laboratories, Fort Monmouth. The specimens were 11" x 2" x 1/8" and the electrodes were tapered pins (Navy Spec. 17-P5, par. F-2g). The results are given in the table below, resistance values in megohms.

Material	As received	Immersion in Distilled Water at Room Temp. 1 day	2 days	5 days	10 days
X	4.1×10^5	430	150	54	
XXP	4.2×10^5		290	29	5
XXX	2.2×10^6	4.5×10^5	1.4×10^5	3.4×10^4	6.5×10^3
C	1.5×10^4	280	75	18	
L	6.3×10^3	45	40	20	6
A	220	47	26	8.1	3.6
AA	1.9×10^3	17	10		4.1
NDP	8.0×10^4	730	530	280	31
GBE	2.3×10^6	6.9×10^3	1.8×10^3	610	250

The data for some of the materials are shown graphically in Fig. 6. In the same series of tests, measurements were also made with screw and washer electrodes (ASTM, D-257-38). In general the resistance values obtained with the screw electrodes are somewhat lower than those obtained with the tapered pins, and not as consistent.

From the same laboratory we also have some data on the change of volume resistivity with time of immersion in distilled water at 27°C and 55°C for a molded phenolic (MTS-E3, MFE). The samples were discs of 4" diameter and 1/8" thickness and the measurements were made in accordance with ASTM, D257-38, after 1, 5, 10 and 15 days of immersion. Before immersion the specimens were kept for 48 hours at 50°C, cooled down to room temperature in a desiccator and measured. Each of the values given below is the average for two specimens.

Before Immersion	Immersion in Distilled Water at 27°C 1 day	5 days	10 days	15 days
4.6×10^{12}	1.3×10^{12}	1.5×10^{12}	5.1×10^{11}	9.6×10^{11}

Before Immersion	Immersion in Distilled Water at 55°C 1 day	5 days	10 days	15 days
2.5×10^{12}	5.3×10^{11}	1.2×10^{11}	6.4×10^{10}	2.6×10^{10}

The values of volume resistivity are given in ohm cm. At 27°C, fifteen days of water immersion causes the volume resistivity to decrease to approximately one fifth of its original value, though some of the intermediate values appear erratic. At 55°C the resistivity drops to about one hundredth of its original value in 15 days.

The effect of prolonged immersion in 50°C water on volume resistance of discs molded from mica-filled phenolic molding material was also investigated at Fort Monmouth. The results are given in Fig. 7 without comment.

II. Power Factor, Dielectric Constant, Loss Factor.

A. Effect of Exposure to Air of High Relative Humidity

There are scattered data available on this subject, but none showing the progressive change in power factor, etc., with prolonged exposure of materials to a humid atmosphere. The following results are from measurements made in the Formica laboratories. The samples were 1/8" thick and the electrodes 4.47" in diameter. Measurements were made at 60 cycles.

Material	I As Received		II After 48 hrs. at 50°C		III Condition II followed by 96 hrs. at 27°C, 90% RH	
	PF	K	PF	K	PF	K
XX	0.032	4.8	0.027	4.8	0.047	5.1
XXX	0.043	5.2	0.036	5.2	0.079	5.7
CE	0.34	11.3	0.25	8.9	0.36	13.1
GBE	0.02	4.6	0.017	4.5	0.061	5.1

Reference was made above to the work done at the Fort Monmouth laboratories on the relative effect on electrical properties of different humidity (and temperature) cycles. These cycles were described, and identified by the numbers 1, 2 and 3. The table below gives data on the progressive effect of humidity cycle 1 on power factor, dielectric constant and loss factor of two specimens, #6 and #17, of molded phenolic (MTS-E3,MFE) in the form of discs of 4" diameter and 1/8" thickness. Before the cycling started, the specimens were kept at 50°C for 48 hours, cooled down to room temperature in a desiccator and measured. All measurements were made at 1 kilocycle, 1 megacycle and 10 megacycles.

It is interesting to note how the effect of this conditioning becomes less important the higher the frequency, which is what one would expect.

	1 KC			1 MC			10 MC		
	PF	K	LF	PF	K	LF	PF	K	LF
Initial Values									
#6	.0492	5.61	.276	.0191	4.92	.0940	.0170	4.80	.0816
#17	.0475	5.63	.268	.0190	4.87	.0925	.0169	4.76	.0804
Average	.0484	5.62	.272	.0191	4.90	.0933	.0170	4.78	.0810
After 5 cycles									
#6	.0828	6.43	.532	.0333	5.13	.171	.0277	4.96	.137
#17	.0744	6.11	.455	.0300	4.98	.149	.0245	4.85	.119
Average	.0786	6.27	.494	.0317	5.06	.160	.0261	4.91	.128
After 11 Cycles									
#6	.0920	6.39	.588	.0300	5.08	.152	.0241	4.90	.118
#17	.0837	6.15	.515	.0290	4.98	.144	.0228	4.85	.111
Average	.0879	6.27	.552	.0295	5.03	.148	.0235	4.88	.115
After 15 cycles									
#6	.111	6.82	.757	.0355	5.16	.183	.0283	4.97	.141
#17	.100	6.51	.651	.0324	5.07	.164	.0254	4.90	.125
Average	.106	6.67	.704	.0340	5.12	.174	.0269	4.94	.133

The progressive effect of Humidity Cycle 3 on the power factor of specimens of the same material (MTS-E3, MFE) is shown in the following table:

	1 KC	1 MC	10 MC
48 hours at 50°C	0.0503	0.0203	0.0183
6 cycles	0.1210	0.0412	0.0352
13 cycles	0.1320	0.6506	0.0431
19 cycles	0.1780	0.0619	0.0539
26 cycles	0.3120	0.0825	0.0782

B. Effect of Water Immersion

The effect of 24 hours immersion in water at room temperature on the dielectric constant and power factor at 60 cycles of four different materials is shown in the table below. These results are from the Formica laboratories.

Material	I As Received		II After 48 hours at 50°C		III Condition II followed by 24 hours immersion in water at r.t.	
	PF	K	PF	K	PF	K
XX	0.032	4.8	0.027	4.8	0.030	4.8
XXX	0.043	5.2	0.036	5.2	0.050	5.4
CE	0.340	11.3	0.250	8.9	0.331	11.2
GBE	0.020	4.6	0.017	4.5	0.043	4.8

From the same laboratories we also have some data on the effect of immersion in water of different temperatures for XXXP material, at 1 KC and 1 MC, as follows:

	1 KC			1 MC		
	PF	K	LF	PF	K	LF
Initial Values	.0536	5.59	.300	.0303	4.9	.147
After 24 hrs. in water at room temperature	.187	6.99	1.28	.0408	4.88	.200
After 48 hours in water at room temperature	.257	8.17	2.10	.0444	5.15	.228
After 48 hours in water at 50°C	.343	10.0	3.43	.0535	5.24	.280

Along the same lines are the following data from the Synthane Corporation on power factor at 1 megacycle:

Grade	Initial Value	After 24 hrs. in water at 25°C
C	.055	.080
L	.055	.075
X	.045	.055
XX	.042	.045
XXX	.040	.042
XXP	.034	.037
XXXP	.024	.026

A group of data drom Fort Monmouth covers a longer period of immersion, fifteen days, in distilled water at 27°C and 55°C. The samples were discs of molded mica-filled phenolic (MTS-E3,MFE), the same material for which many other data have been given in this report. Before immersion, the samples were kept for 48 hours at 50°C, then cooled down to room temperature in a desiccator for the initial measurements. Power factor, dielectric constant and loss factor were determined at 1 kilocycle, 1 megacycle and 10 megacycles, with the following results:

Specimens immersed in Distilled Water at 27°C

	1 KC			1 MC			10 MC		
	PFm	K	LF	PF	K	LF	PF	K	LF
Before Immersion	.0481	5.57	.268	.0186	4.89	.0909	.0168	4.80	.0803
After 1 day	.0538	5.68	.306	.0207	4.94	.102	.0177	4.84	.0857
After 5 days	.103	6.51	.671	.0353	5.08	.179	.0304	4.90	.149
After 10 days	.144	7.31	1.06	.0453	5.34	.242	.0402	5.05	.202
After 15 days	.169	8.06	1.36	.0511	5.49	.280	.0465	5.16	.240

Specimens immersed in Distilled Water at 55°C

	1 KC			1 MC			10 MC		
	PF	K	LF	PF	K	LF	PF	K	LF
Before Immersion	.0517	6.16	.319	.0203	5.33	.108	.0181	5.23	.0945
After 1 day	.110	7.34	.808	.0384	5.62	.216	.0326	5.36	.175
After 5 days	.227	10.6	2.40	.0653	6.61	.431	.0647	5.88	.380
After 10 days	.301	13.9	4.20	.0916	7.24	.664	.0907	6.43	.584
After 15 days	.351	17.41	6.11	.1060	7.97	.845	.111	6.54	.726

From this last group of data it is again apparent how much greater the effect of moisture absorption is at the lower than at the higher frequencies. This is particularly true if we consider the loss factor; there is then a wide gap between the results at 1 KC on the one hand and those at 1 MC and 10 MC on the other, especially at the higher water temperature.

In Fig. 8 are two curves showing the effect of prolonged immersion in distilled water at 50°C on the power factor at 1 MC of two mica-filled phenolic molding compounds, one being the MTS-E3 for which many data have been given, and the other an MTS-E4, classed as a low-loss compound. These curves, too, are from Fort Monmouth.

In addition to the heat and humidity cycles described above, and the straight water immersion, the Signal Corps laboratories have also been using a water immersion cycle as follows:

55°C water for 6 hours
27°C water for 6 hours

The effect of this water immersion cycling on the power factor of the MTS-E3 material is as follows:

	1KC	1MC	10MC
Initial Value	.0499	.0198	.0179
6 cycles	.2260	.0598	.0548
13 cycles	.2740	.0841	.0812
19 cycles	.4250	.1050	.1015
26 cycles	.4620	.1100	.1140

As before, the samples were kept for 48 hours at 50°C before the initial measurements were made (at room temperature).

It was mentioned above that these different methods of humidity and water immersion cycling were investigated at Fort Monmouth in order to determine which was the most severe from the point of view of its effect on electrical properties. The conclusion drawn from this comparative study is that water immersion is more severe than exposure to heat and humidity (under the conditions stated). Fig. 9 is a graphical picture of results on which this conclusion is based. It shows the variation of the dielectric constant of our MTS-E3 compound with time of exposure to the water immersion cycle and the humidity cycle identified as "Humidity Cycle 3" above. Since both cycles are of 12 hours duration, it will be seen that the dielectric constant seems to approach limiting values near 26 cycles of the water immersion both at 1 KC and 1 MC, while many more humidity cycles would be required to come close to those values. Similar curves were found for the power factor.

III. Mechanical Properties

In the material which has been made available in the present survey there is very little worth mentioning at this point. The effect of exposure to moisture on volume resistivity, power factor and dielectric constant is, of course, a reflection of the water absorbed by the insulator. Since moisture absorption changes the weight and, in general, the volume of an insulator, the study of moisture absorption, per se, may be said to come under the category of mechanical properties. Fig. 10 shows the progressive absorption of water by mica-filled phenolic molding compounds immersed in water at 50°C. These curves, which are from the Signal Corps laboratories, become of particular interest when compared with the curves in Fig. 8 which give the progressive change in power factor for the same materials, under the same conditions.

In the Works Laboratory of the General Electric Company at Schenectady an investigation has been going on for the past couple of years dealing with the question of dimensional changes of laminated phenolic plastics exposed to a humid atmosphere at room temperature. The following data show the percentage dimensional changes for different materials, referred to the "dry" state, after conditions had become stationary in an atmosphere of 100% relative humidity at room temperature. The specimens were 4" x 0.9" x 0.07".

Laminated Samples	% Dimensional Changes		
	Length	Width	Thickness
Cotton	0.35	0.6	1.3
Asbestos	0.15	0.2	0.7
Glass	0.12	0.2	0.7

Conclusion

As stated in the beginning the present report does not pretend to give a complete story of all recent work having to do with the effect of moisture and fungus on the properties of plastic insulating materials. It does, however, present a judicious selection of the experimental material made available to the writer as a result of the recent visits to various laboratories described above. It should be worth while to write a complete report when all available data have been brought together.

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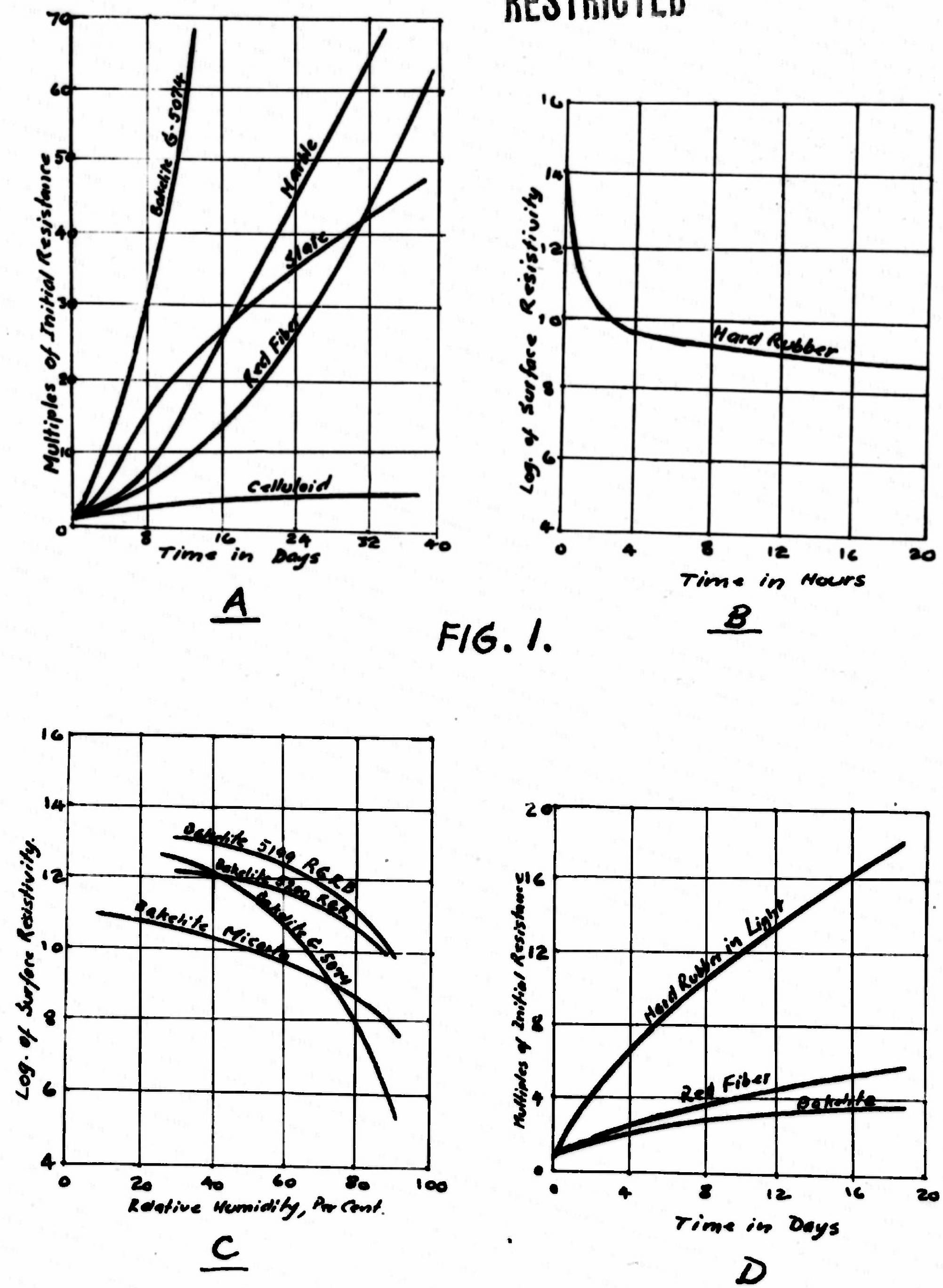

FIG. 1.

FIG. 2

EFFECT OF HIGH HUMIDITY AND FUNGI ON THE D.C. RESISTANCE OF VARIOUS INSULATING MATERIALS

TEMPERATURE 25°C., RELATIVE HUMIDITY 97%; EXCEPT WHERE NOTED OTHERWISE

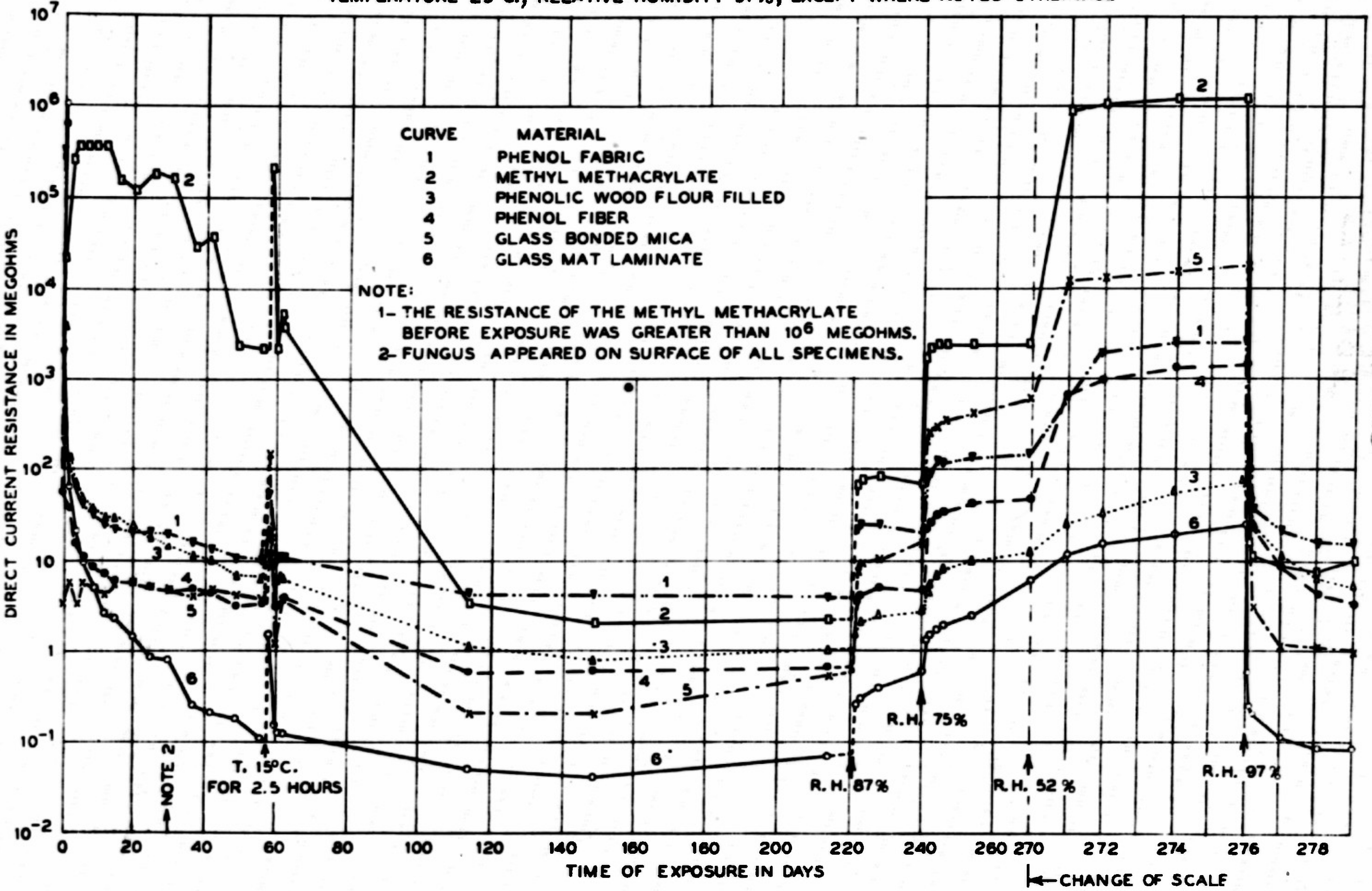

FIG. 3. RESTRICTED

COMPARISON OF THE D.C. RESISTANCE
OF PHENOL FABRIC AND METHYL METHACRYLATE
AT 100 % AND 97% RELATIVE HUMIDITY

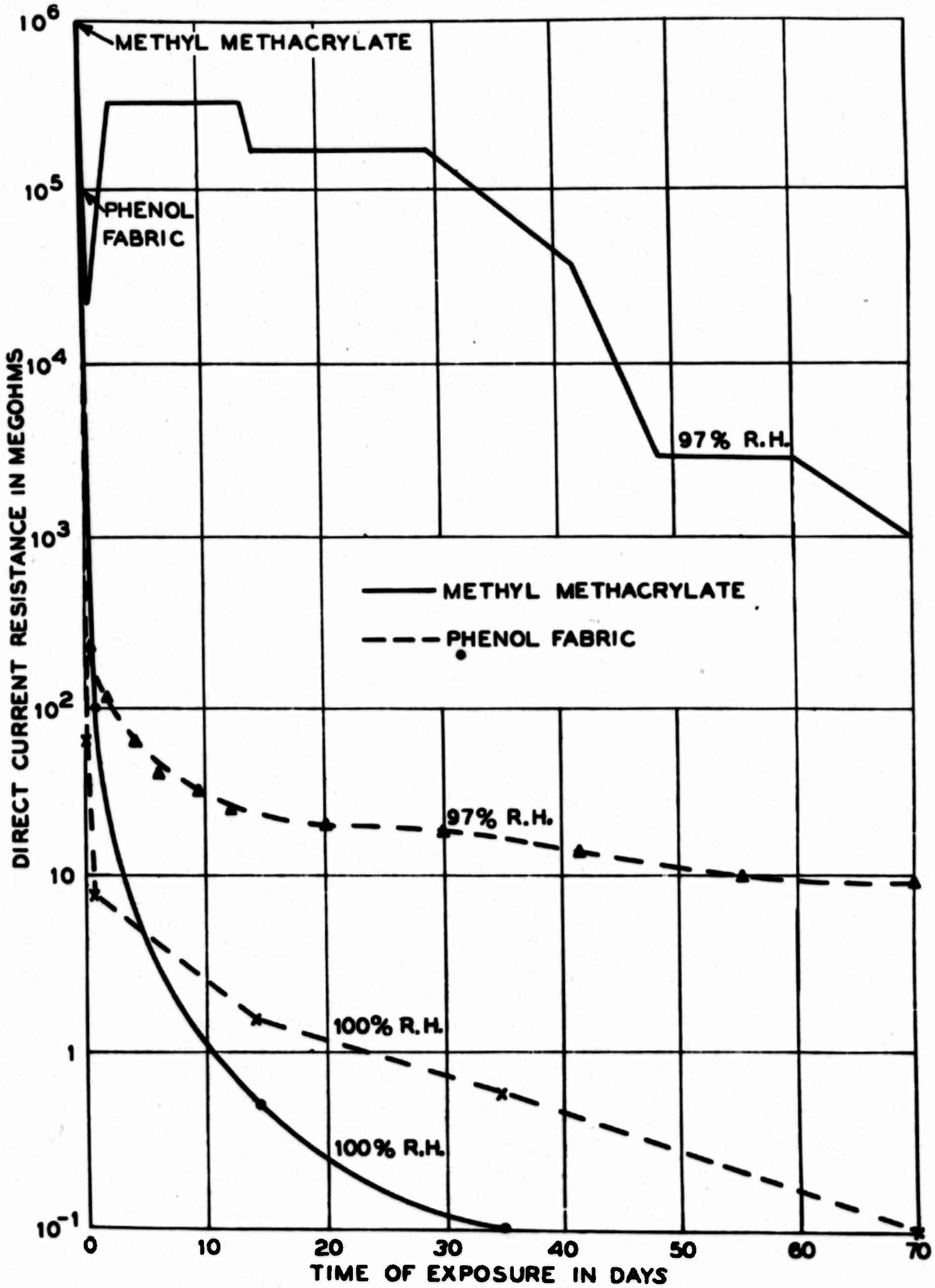

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FIG. 4.

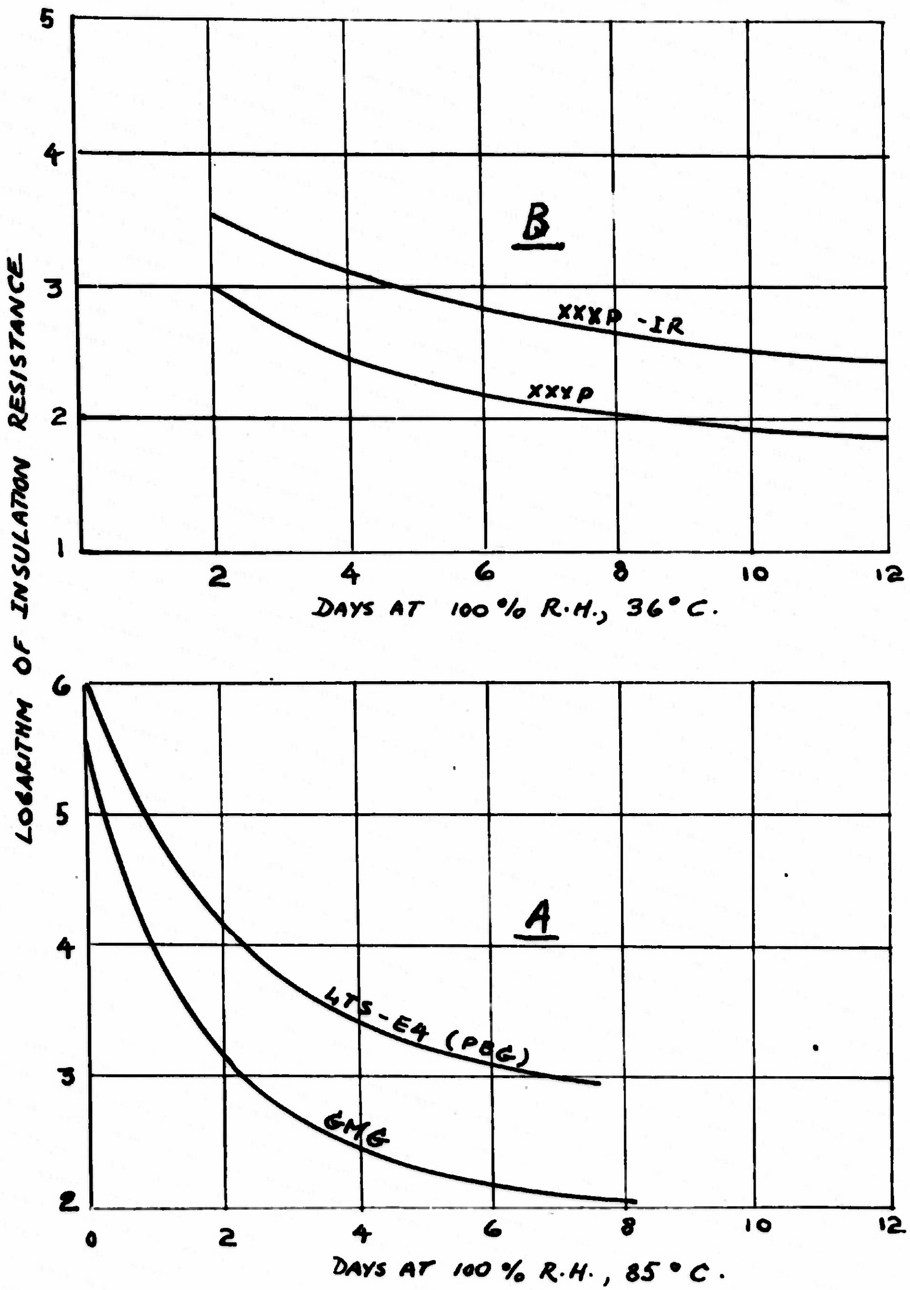

TABLE 1

Effect of Atmospheric Condensation on Insulation Resistance of Molded Phenolic Terminal Block

(Untreated)

	Test No.	Initial Ins. Res. Before Test Megohms	Temp. of Blocks Preceding Humidity Exposure F	Max. Effect of Condensation on Ins. Res. of Blocks		Changes in Ins. Res. in Megohms After Exposure to 90% RH at 85F							
						Time of Exposure							
						Minutes							Hours
				Min. Ins. Res. Reached Megohms	Time to Reach Min. Ins. Res. Minutes	15	30	45	60	100	150	175	19
Block #1	1	3,220	+30	8.6	22	10	9.4	10.7A	10	—	20	—	—
Block #2	1	3,400	+30	7.8	32	11	7.9A	9.5A	10	—	16	—	—
Block #1	2	17,600	0	18.3	36	43A	21A	24	25	25	35	—	—
Block #2	2	5,500	0	10	75	79	25	18	13A	14	16	—	—
Block #1													
Block #2	2A*			1.2	at once	Distilled water poured over Block #2 while in Humidity							
Block #1	3	38,400	+30	22	15	22	23	24	26	60	72	—	72
Block #2	3	13,000	+30	22	72	50	32	30	26	28	45	—	100
Block #1	4	38,400	+30	22	30	29	30	23	28	30	—	50	—
Block #2	4	11,300	+30	22	105	67A	41	32	31	22	—	25	—
Block #1	5	740	+30	6.5	51	14	9	7.5	6.5	7.5	10	—	60
Block #2	5	740	+30	10.0	101	65	30	20	14.0	11	11	—	82
Block #1	6	44	+30	4.0	67	7.3	5.0	4.6A	4.4	5.3	7.0	—	—
Block #2	6	68	+30	10	84	33	18	12	11.3	10	10.5	—	—
Block #1	7	33	—33	1.9	55	5.5	2.5	2.0	2.0	2.4	3.5	4.2 (217 min.)	
Block #2	7	56	—33	2.8	90	25	6.0	4.2	3.6	3.0	3.0	3.2 (217 min.)	

NOTES

1 Block #1 mounted horizontally with terminal punchings vertical.
Block #2 mounted horizontally with terminal punchings horizontal

2 Data marked (A) obtained by interpolation between two nearest readings.

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FIG. 5.

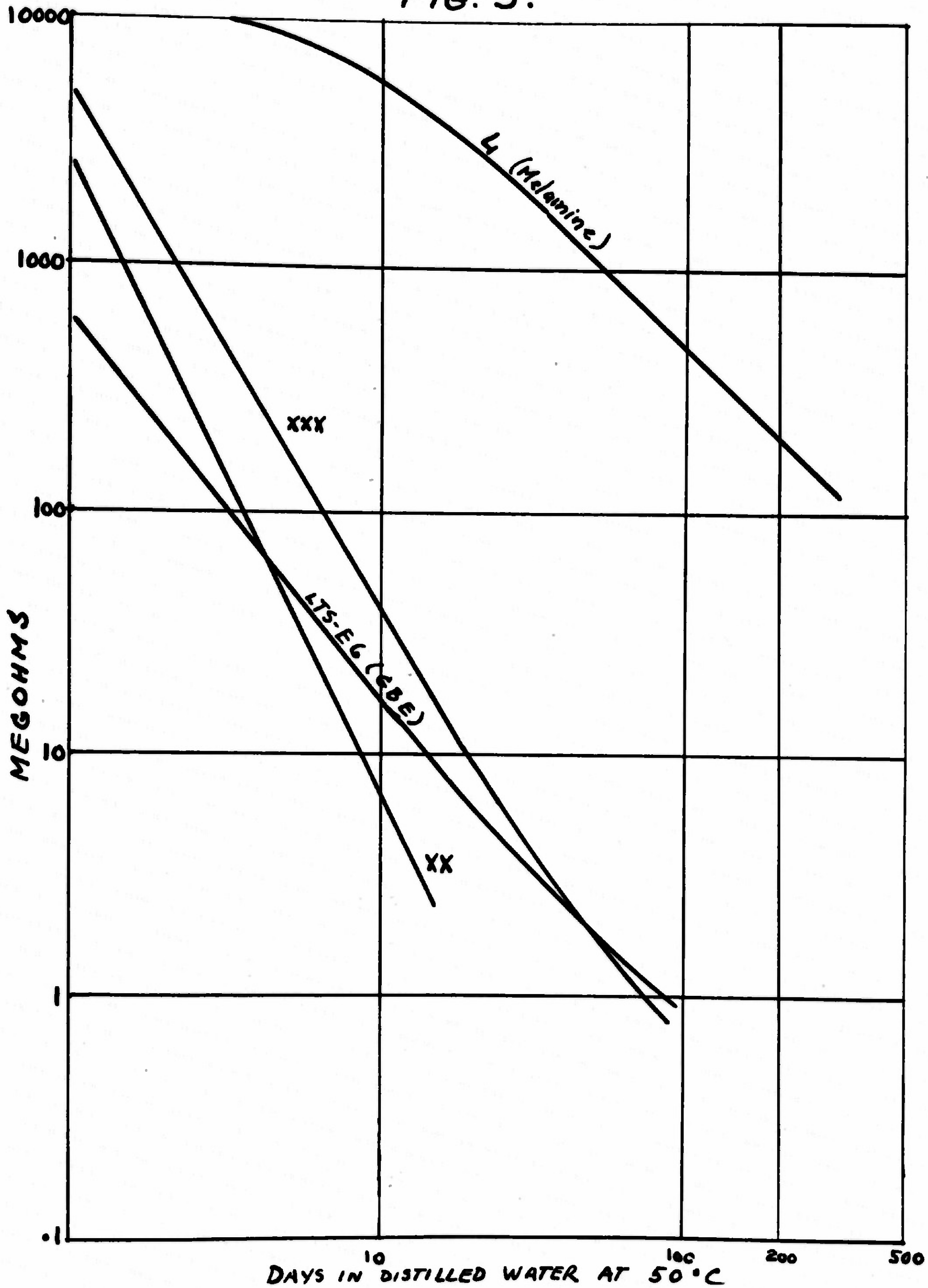

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FIG. 6.

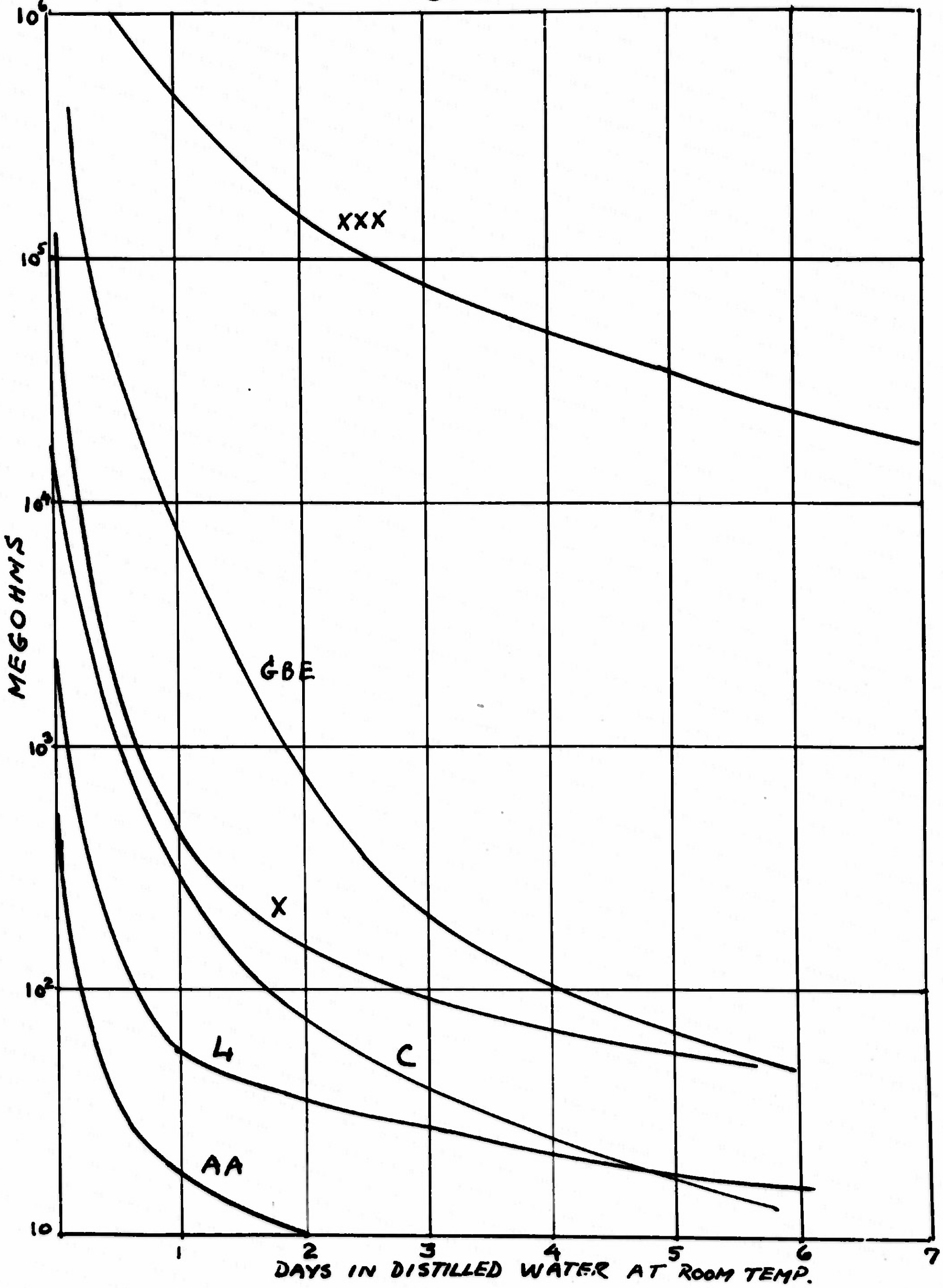

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FIG. 7.

EFFECT OF PROLONGED IMMERSION IN WATER AT 50°C ON VOLUME RESISTANCE OF MICA-FILLED PHENOLIC MOLDING MATERIAL.

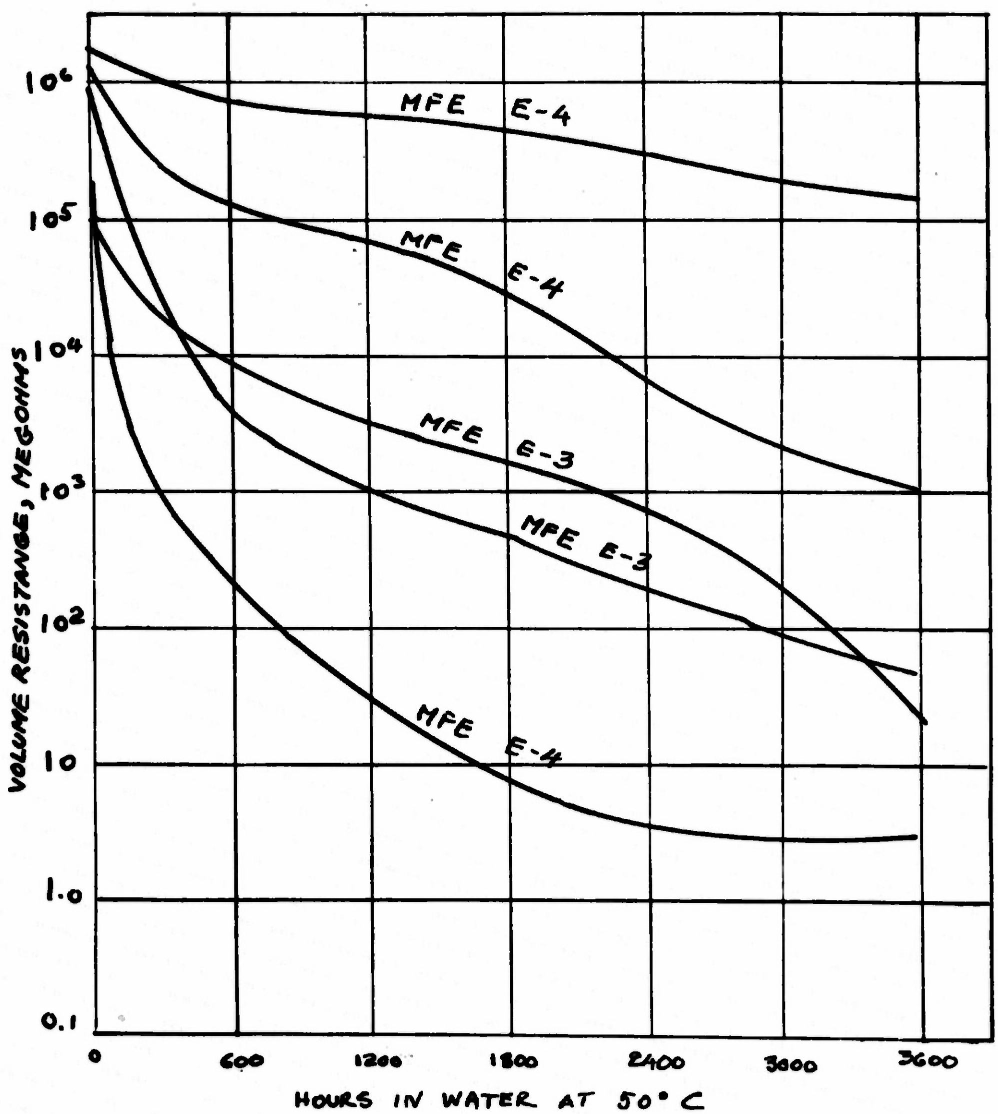

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FIG. 8.

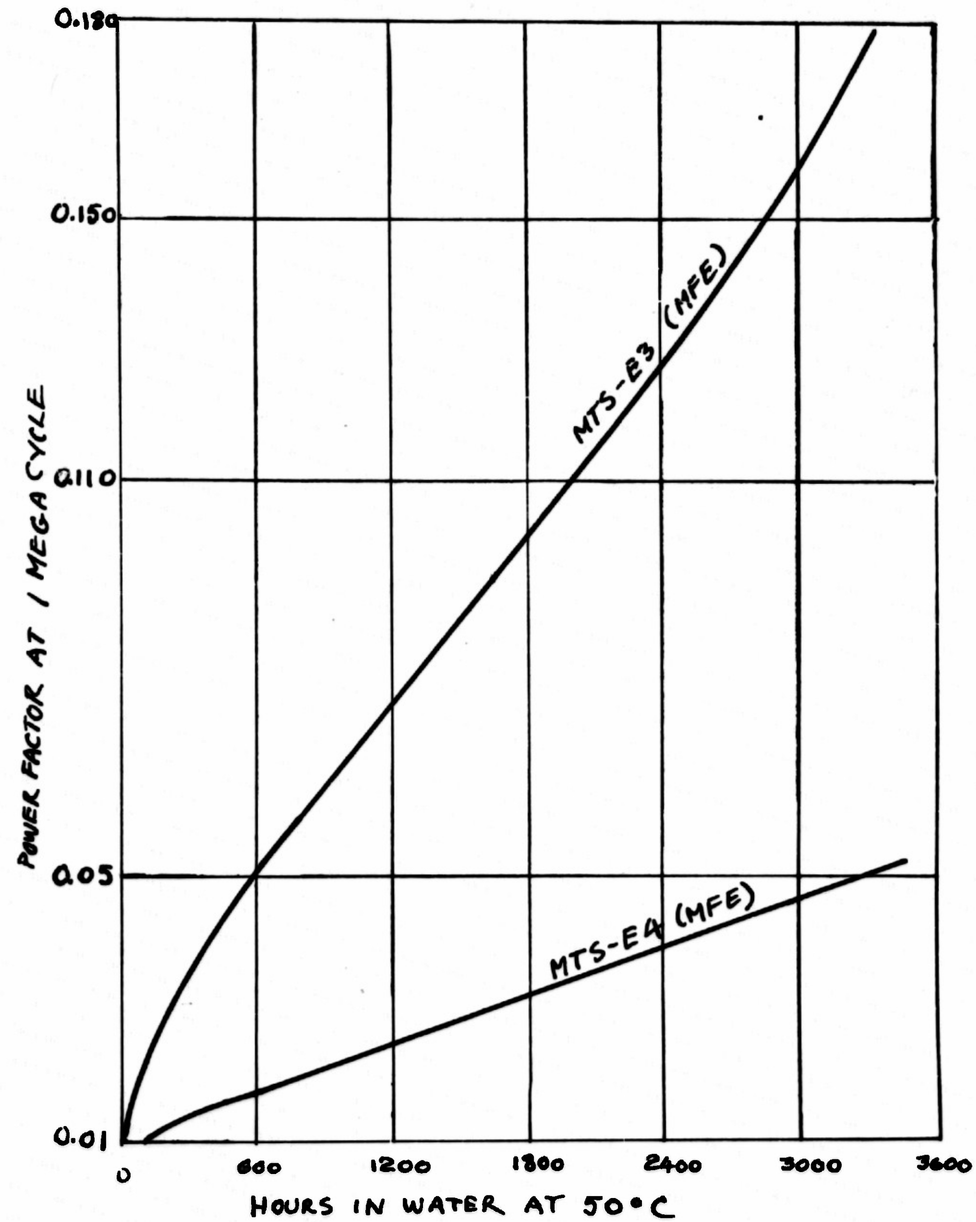


FIG. 9.

EFFECT OF CONDITIONING ON DIELECTRIC CONSTANT
OF MTS-E3 (MFE)

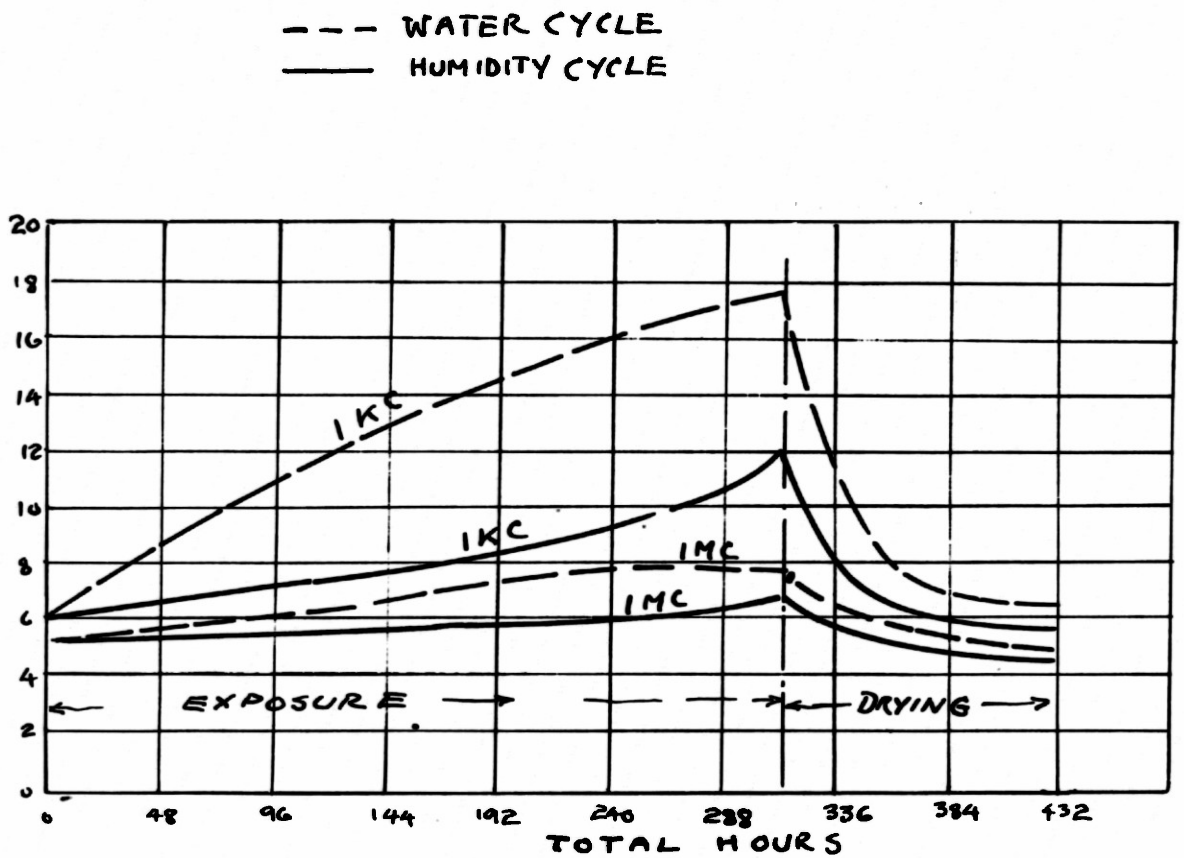
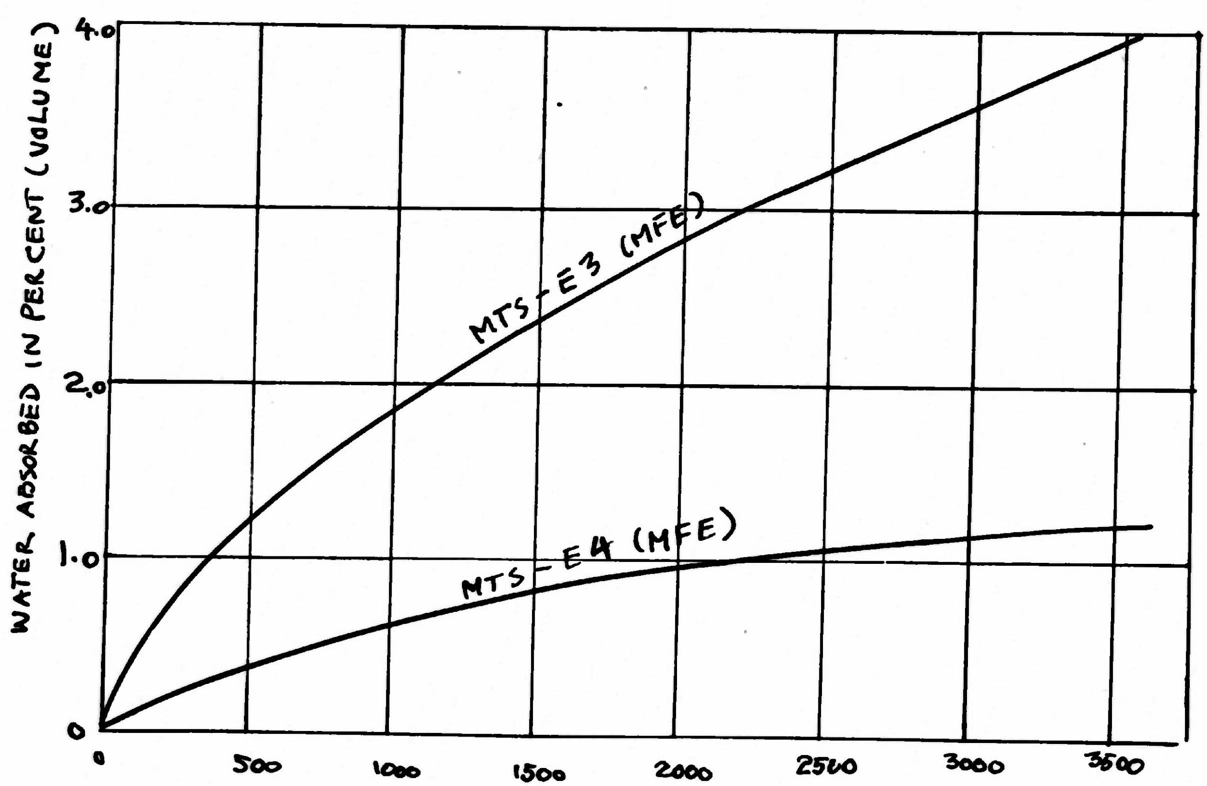


FIG. 10.

WATER ABSORPTION OF MICA-FILLED PHENOLIC MOLDING MATERIAL.



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ABSTRACT:

The effect of moisture and fungus on electrical and mechanical properties of plastic materials has been investigated. Those materials which are the most porous, naturally, deteriorate more rapidly, and to a greater extent, since they absorb water more readily. It is obvious that when noisture is present in the material, its insulating properties are seriously reduced. The effect of fungus is to increase the amount of moisture absorbed. The results of the investigations of many different types of plastics are given in tabular form.

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